**GOING NUTS**

Developing Peanut Shell Fuel Briquettes for Household Use in Malawi

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# 1 Abstract

Deforestation resulting from fuel wood demand is a major concern in sub-Saharan Africa. In largely agrarian Malawi, wood composes 90% of cooking fuel. We propose a substitute fuel made from agricultural wastes, primarily peanut shells, to reduce deforestation, improve household health, and provide an additional source of income to farmers.

Peanut shell briquettes were made of a variety of recipes and forms and were peer evaluated to determine the design that had the best durability and aesthetics, because these two characteristics are seen to be significant barriers to adoption of a new fuel source. A 1:6 wet yucca to peanut shell ratio was the most effective binding agent and recipe when made in a 2-inch diameter donut. These briquettes were burned in a qualitative trial, where it was found they could not be lit on their own. Peanut briquettes are best used as a supplement to an ongoing fire rather than as a fire starter.

Emissions tests were performed on this briquette recipe to determine gasses being produced when used as fuel for a Berkeley Darfur Stove. CO2, CO, PM2.5, and black carbon were measured. Results show that these four emissions were 50-150% greater from burning peanut briquettes than from wood.

Production capacity, marketability, and ownership practices in Malawi all suggest that a peanut briquette making system would be most effective at a centralized large-scale producer rather than at a smaller scale.

Although a successful peanut briquette has been designed, evaluated, and tested, the economic and ecological barriers to adoption are sufficient for us to recommend against the large-scale development of peanut briquettes. Future work should focus on determining if peanuts are superior to other agricultural wastes while also investigating the significance of binder choice to the briquette emissions profile before proceeding to further develop a briquette production system.

## Table of Contents

## 2 Background and Context

Malawi is a country in southern Africa with a population of about 8 million people, 70% of which are below the national poverty line. As of 1998, the main energy source for cooking was fuel wood, making up about 90% of all cooking fuel [1]. Wood charcoal is used to a lesser extent and very few people use agricultural waste. Deforestation has raised concerns over fuel wood availability, and decreasing woodsheds require women to spend significant time collecting wood and illegally collecting from government-protected areas out of necessity. Furthermore, the smoke from use of fuel wood is known to cause acute respiratory infection (ARI) to adults and children [2]. This has prompted research into both stove efficiency and alternate fuel sources. Since Malawi is a highly agrarian region, agricultural waste may be a viable substitute for fuel wood and wood products.

The Full Belly Project (FBP) is a non-government organization (NGO) that designs and distributes income-generating agricultural devices to improve life in developing countries. FBP developed the Universal Nut Sheller (UNS) to increase the rate of shelling peanuts and has recently taken on the challenge of using the peanut shells to create briquettes that may be used in place of fuel wood or wood charcoal. Our team worked with FBP February – May 2010 to create an effective peanut shell briquette design and test the emissions.

## 3 Team Goals

Ultimately, we wish to contribute to improve livelihoods by displacing wood use, thereby slowing local deforestation and saving households either time or money. We also wish to improve the health of households by limiting harmful emissions from biomass fuels. We set as our goal the design and production of a peanut shell briquette that is easy to use, affordable, utilizes locally available materials, and burns well while emitting fewer/less harmful emissions than comparable biomass feedstock (i.e. fuel wood or charcoal).

This report describes our process and findings over the months of February – May 2010. We describe a “good enough” briquette option, realizing we lack the time to find the “optimal” design. Our intention was to delineate the different factors to consider when making briquettes so that others may better innovate on what we produced. Furthermore, we recognize that the design of a product is ultimately the design of a process as well, and we have attempted to capture relevant details with respect to production equipment and implementation models.

# 4 Research and Findings

## *4.1 Press and Briquette Design*

### 4.1.1 Introduction and Overview of Process

Peanuts, also called groundnuts, ground-peas, earthnuts, pindar, jar-nut and manila-nut, are the pea-like fruit from the Arachis hypogaea plant, which is part of the bean family. There are several varieties of peanuts throughout the world. The peanuts that are available in Africa are called Spanish Peanuts and have smaller, rounder nuts that are tight against the shell compared to Virginia peanuts, which are typically found throughout the United States [3].

The chemical composition of peanut shells is 8.2% protein, 28.8% lignin, 37.0% cellulose and 2.5% carbohydrate [4]. The chemical concentrations of Spanish and Virginia peanuts are very similar with Spanish peanuts having only slightly lower oleic acid concentrations [5]. The affect of peanut variety on the effectiveness of burning has not been researched, however since the chemical composition is the same and the chemical concentrations are not significantly different we do not believe the variety will have a significant influence on the results. For our testing we used raw in-shell Virginia peanuts due to their availability.

The briquetting process starts with passing the raw in-shell peanuts through the UNS and collecting the shells and nuts. After separating the nuts from the shells, which took a considerable amount of time, we adjusted the UNS so the space between the inner wall and outer wall is decreased. We passed the shells through the adjusted UNS, resulting in a finer ground.

We used various binders mixed with the grounds to provide cohesion between particles and strength to the briquette. To conserve materials, we used only enough binder to enable us to mould the mixture. We used three different presses to achieve various briquette shapes. Once pressed, we left the briquettes under a fume hood at room temperature to dry. Drying times ranged from two days to 17 days.

Key variables that we looked at include briquette size, shape and density, binder material, grain size distribution and durability. We qualitatively assessed each variable (and quantitatively when possible) to choose a good option for each. The importance and variations of each is discussed below.

### 4.1.2 Briquette Press

The Full Belly Project (FBP) sent us the three presses depicted in Figure 1 below. Two of the presses (Presses A and B) each had the capability of producing one briquette at a time, while the third press (Press C) was meant for mass production. Initially, in the briquette design phase we tried presses A and B since they were easy to operate and did not require mixing a large volume of ground peanut shells and binder (as was required for the high volume press) since a working binder-to-shell ratio was yet to be discovered.

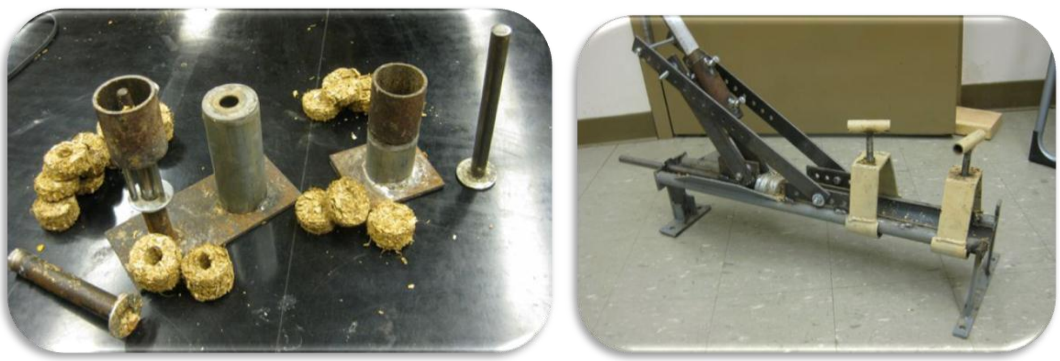

**Figure 1:** Three presses that were used to produce A. donut (left), B. puck (middle), and C. extruded briquettes.

Press A consists of a cup with a rod in the center and a plunger with a hole to accept the rod. This press produced a donut-shaped briquette (see Figure 2). Press B was slightly simpler; it included all of the components that Press A did, except it did not have a rod in the center of the press and therefore had a solid plunger as well. This press produced a puck-like briquette. Press C produced a less compact briquette, which we have termed the extruded briquette. This press was designed such that the user fed the peanut shell and binder mixture through a tapered cylinder using a long lever arm. The pressure from essentially squeezing the mixture through the cylinder packed the material such that a solid piece exited the press. The user had the option of producing a long briquette log or inserting washers intermittently in between material replenishment so that the briquettes would exit already separated.

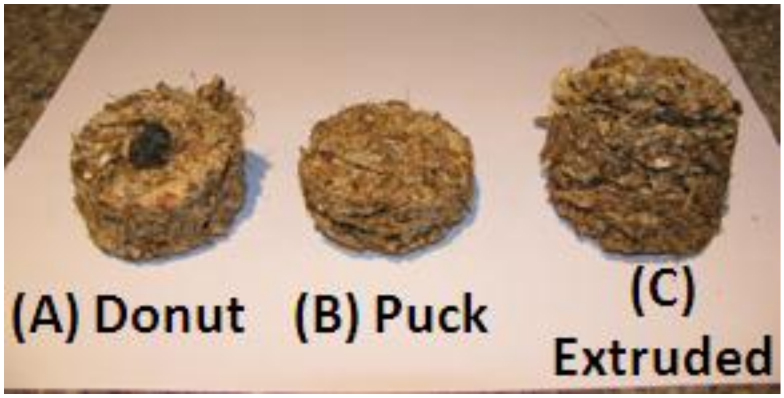


**Figure 2:** Briquette shapes

The presses were designed such that the diameters of the briquettes were constrained, but the thickness was not. After multiple trial runs, we found that in terms of packing the mixture to make a briquette, using a 1/3 c. of mixture and 25 blows with a rubber mallet produced a briquette with good durability (i.e. it did not break after some handling). The approximate dimensions and weights of each shape are summarized in Table 1. Through qualitative testing we found briquettes made from A and B to more user-friendly, therefore for subsequent tests we used only Presses A and B for production.

**Table 1:** Characteristics of briquette types

| Shape | Diameter (in.) | Height (in.) | Weight (g) |
|---|---|---|---|
| Donut | 2 | 1 | 15 |
| Pressed Puck | 2 | 3/4 | 15 |
| Extruded Puck | 2 | 2-3 | 24 - 37 |

### 4.1.3 Size

Varying the briquette size influences the drying time, burning rate, and how often the user must feed the fire. We found that the 1/3 c. of binder-grounds material we used for the donut and puck briquettes was optimal. This gave a reasonable drying time of approximately one day and allowed small additions to the fire as needed. The size of the extruded briquette resulted in longer drying times and even after 15 days, we observed mold within the extruded briquettes, indicating it was not fully dry.

### 4.1.4 Grain size distribution

Processing the peanut shells back through the Universal Nut Sheller (UNS) gave us peanut shell particles ranging from fine particles of less than 850 microns to approximately 16 mm. A study on paddy husk briquettes found that the density, durability, and combustion efficiency increases with decreasing particle size [6]. Density is increased because particles fill in the gaps between the larger particles, which would otherwise be air pockets. There is conflict between researchers regarding the optimal particle size, which is claimed to be between 3 and 8 mm [7-9]. Additionally, although some fines smaller than 1mm are desirable for cohesiveness and allow for less binder to be used, there is debate whether fine grain size decreases the combustion efficiency [10]. It is not possible to create an even particle distribution using the UNS, therefore we analyzed the performance of briquettes made with the grain size distribution produced by the UNS. This is the most likely grinding technique where a UNS is available.

We performed a sieve analysis following the guidelines of ASTM C136-06 [11] to find the peanut shell grain size distribution (GSD). The sieve analysis consists of passing a sample of the material through smaller and smaller sieves then measuring the amount retained in each sieve. Table 2 summarizes the GSD. Other studies have found that GSD between 120-380 μm does not show significant difference in thermal decomposition when burned [12]. It is undetermined if this is true for larger particle sizes and is a potential topic for future research.

**Table 2:** Peanut shell grain size distribution

| **Grain size (mm)** | **Weight %** |
|---|---|
| Larger than 9.51 | 6.47 |
| 4.76 – 9.51 | 28.6 |
| 2.38 – 4.76 | 32.5 |
| 2.00 – 2.38 | 5.40 |
| 1.19 – 2.00 | 11.2 |
| 0.840 – 1.19 | 4.26 |
| Less than 0.841 | 11.5 |

The large distribution of particle size we used for our briquettes allows for a fairly dense briquette while maintaining enough porosity to promote drying and burning. However, there is a fair amount of fine material less than 1.00 mm. Fine particles may inhibit proper burning and future burn tests should be conducted with most fine particles removed to determine the affect.

### 4.1.5 Binder and Durability

Finding an adequate binder and binder-to-shell ratio were some of the most challenging aspects of this project. The Legacy Foundation's Briquette Manual [13] initially helped with the briquette-making process, but the manual was limiting in that it did not mention which composition of binder materials was most efficient since the information related to binders was primarily qualitative. In choosing a binder we wanted a material that would be readily available in Malawi. Communication with Amanda and research into the agricultural crops grown in the South Eastern part of Africa led us to try starches and cassava-based binders [14].

We first experimented with a corn starch binder. We added water to corn starch until it was at the solid-liquid state (i.e. it turned to liquid when stirred). Following the Legacy Foundation's manual, we mixed the binder with the peanut hulls until when compressed in the palm of our hand, we observed some spring-back. We pressed the mixture and allowed the briquettes to dry overnight, indoors underneath a vent and found that the briquettes would break into 3 or more pieces after being transported, even if handled with care.

We ran more controlled briquette-making sessions and made binders with either a corn starch, tapioca or plantain base. We tried both dry and wet tapioca; for the wet tapioca we allowed tapioca pellets to sit in water overnight which resulted in a gelatinous mixture. The plantain-based binder was mixed with water and boiled until it formed a thick sludge. In considering the written instructions for future users, we decided to simplify the binder-making process as much as possible so that we would work with parts, i.e. 1 part water to 2 parts flour to 5 parts peanut shells (1:2:5). We also wanted to minimize binder use since it would be a costly material considering that the peanut shells are a waste product, but the binder material would need to be purchased or harvested specifically to make the briquettes. We therefore sought our limits as to the binder-to-shell ratio so that the briquette would not fall apart immediately after being removed from the press and concluded the following as adequate ratios:

- (1:1:2.5) 1 part water to 1 part corn starch to 2.5 parts peanut shells
- (1:1:3) 1 part water to 1 part tapioca flour to 3 parts peanut shells,
- (1:4) 1 part plantain mixture to 6 parts peanut shells,
- (1:6) 1 part wet tapioca mixture to 6 parts peanut shells.

During our midterm design review feedback session in March of 2010 we handed out three briquettes to each of the four project teams and asked the teams to rate the looseness, transportability, and aesthetics of the briquette on a scale of 1 to 5 (see section 9.1 in the Appendix for questions and a summary of the results) where 1 was a highly desirable state and 5 was very undesirable. We also asked our classmates to discuss at least one of three questions relating to briquette ignition, the use of food as a binder, and the notion that agricultural waste is already used in some areas to make briquettes. From the feedback session, only briquettes made with a 1 to 4 ratio of plantain binder and a couple made with wet tapioca binders survived. The wet tapioca based briquettes rated the best in all three categories. It was useful to note that no briquettes made with a flour-based binder survived.

The looseness and transportability of the briquette are two qualities that are closely related. A very durable briquette would survive transportability far beyond the place of purchase. The aesthetics of the briquette is a factor that we considered since the briquette is a product that would be purchased to displace the use of wood charcoal. If the briquettes became moldy or it seemed to be breaking apart, then an individual would not want to purchase briquettes. There was not much of a difference amongst the different briquettes in terms of aesthetics, and the looseness and transportability ratings were found to be similar (see Figure 3). Averaging our results we found that the plantains (1:4) and wet tapioca (1:6) based binders had the best ratings (see Figure 4Figure 4). Considering the possibility for future surveys, the user's value of durability and ease of use (relative to wood) should be measured. Durability would encompass what we were trying to achieve with the looseness and transportability factors. Ease of lighting would have been a very useful measure as well, but we were not able to burn the briquettes during the session because it would present a fire hazard.

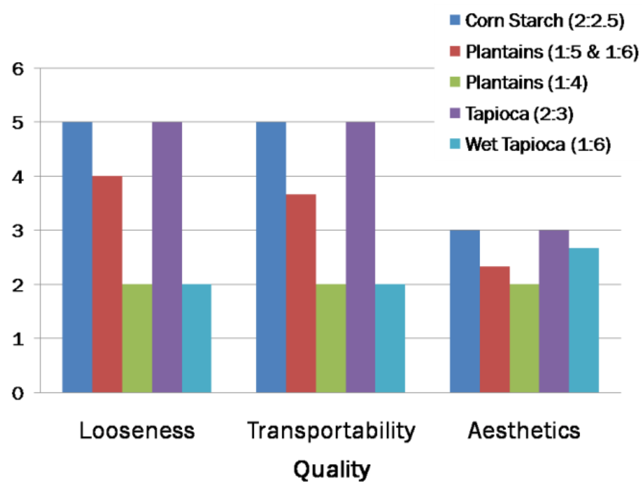


**Figure 3:** Results from in-class feedback session

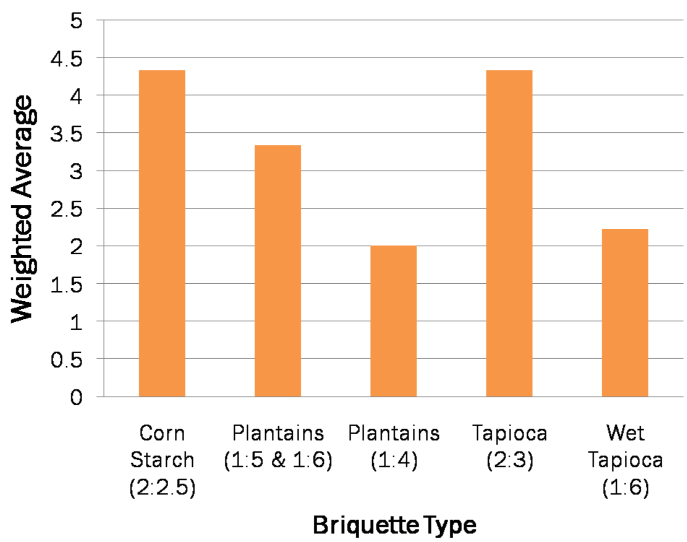


**Figure 4:** Average rankings for 5 briquette types from in-class feedback session

The feedback session gave us direction in choosing a working binder and binder to shell ratio. Yucca (cassava) was introduced as a potential binder after the midterm feedback session. It is much less expensive than plantains. However, the yucca mixture must be created by boiling the yucca in water for ten minutes then mashing it and mixing with 1/8 cup of water per pound to get the binder to a sludge state. The yucca-based briquettes were made from 1 part yucca mixture to 6 parts ground peanut shells. Once the combined mixture was pressed, the briquettes were allowed to dry overnight and these were the briquettes used in the emissions testing.

### *4.2 Qualitative Combustion Testing – Ease of Use*

By performing qualitative combustion tests with each briquette shape we were able to identify potential problems that a user may encounter as well as if one type of briquette was easier to use than the others. The peanut shell briquettes in general do not burn as well as wood. We were unable to ignite the briquettes without an established wood fire. We added briquettes to an established fire sparingly but fast enough to keep a healthy flame. The donut briquette ignited quicker than the puck or extruded briquettes. We believe this is likely due to the additional surface area from the center hole. Furthermore, the donut briquette was easier to place because it could be placed flat, while the other briquettes needed to be propped up against another briquette to allow oxygen to the underside to ignite and continue to burn. If we allowed the extruded or puck briquette to lay flat it would smolder and eventually extinguish. Therefore, the donut was easier to ignite and keep burning. We observed that during a flame-out, significant amounts of smoke and unburned gases were produced. Unless an external ignition source was used, we found it difficult to relight the unburned gases during a flame-out from the coals alone.

While using the briquettes in the Darfur stove we realized it was easier to have smaller briquettes, which enabled us to spread the fire out under the pot instead of having one concentrated flame. A smaller briquette also proved to be easier to burn and smoldered less. The size of the extruded briquette resulted in longer drying times and even after 15 days, we observed mold within the extruded briquettes.

### *4.3 Quantitative Combustion Testing - Emissions*

After evaluating the subjective quality of the briquettes, we needed to quantitatively verify performance by performing emissions tests to measure $CO_2$, CO, PM2.5, and black carbon. These four metrics will be used to compare peanut briquette emissions to wood emissions, and have been chosen due to their relevance to both environmental and human health impacts. According to the IPCC in 2007, $CO_2$ is the most significant contributor to global warming and black carbon has an impact on the melting of glaciers and snowpack [15]. The Handbook on Life Cycle Assessment inventory states the remaining two emissions pertain to human health—Raub and Benignus have done extensive work to show CO is an asphyxiant [16-18], while the EPA has published that PM2.5 leads to respiratory issues [19]. Black carbon is additionally a specific type of particulate of interest due to aesthetic impacts and as a factor in radiative forcing [20].

Spatially, $CO_2$ and black carbon have global implications, while PM 2.5, CO, and black carbon have local impacts. Due to the setup of the testing equipment used, a cyclone was used in the testing manifold to prevent fouling of the instrumentation and readings outside the range of the instrumentation. This cyclone had a cutoff of 2.0 microns, affecting our PM emission factors.

An emissions testing protocol has already been developed at Lawrence Berkeley National Laboratory to test cookstove efficiency of the Berkeley Darfur Stove [21]. Due to the availability of these materials and this testing setup, we used a modified version of the Assida test protocol. The protocol calls for raising 2.5L of water up to 100°C and holding it there for 15 minutes by starting a small wood fire inside a Berkeley Darfur Stove. For our test we used a stove that was not modified with insulation around the fire ring, a large Mullah pot that was partially lidded while containing a spoon with an attached thermocouple to record water temperature. We modified the protocol by changing the fuel from wood to peanut briquettes. Because briquettes currently are unable to be started on their own, a small mass of wood (roughly 30-40g) was lit as a starter, and then the fire was sustained with only peanut briquettes. Four trials were performed, all of which collected data on all four metrics. Peanut briquettes used in the trials were made from a 6:1 ground peanut shells to yucca mixture by volume and weighed roughly 15g after drying. Feed rate was constant enough to hold the water at a boil, and consisted of about one briquette every 1.5 to 2 minutes.

Tests were conducted with the assistance of Dr. Thomas Kirchstetter and Dr. Odelle Hadley using the stove emissions testing facility located at Lawrence Berkeley National Laboratory. Emissions data is presented below in Table 3. Emissions values were calculated by taking a mean value from the trials performed. We see that emissions from burning peanut briquettes are anywhere from 50-180% greater than emissions from burning wood. Complete data on all trials can be found in the appendix.

**Table 3:** Emissions from Wood and Peanut Briquettes during an Assida test in a Berkeley Darfur Stove.

| | Wood (representative trial) | Peanut Briquettes (avg, n = 4) | % Gain |
|---|---|---|---|
| CO2 (PPM) | 3300 | 5000 | 50% |
| CO (PPM) | 130 | 220 | 69% |
| PM 2.5 (PPM) | 7.9 | 22 | 180% |
| Black Carbon (ug/m$^3$) | 98 | 260 | 160% |
| Burn Rate (g/min) | 6.0 | 8.4 | 36% |

Black carbon and CO are indicators for incomplete combustion and both were found in greater concentrations than during wood tests. This suggests that not enough oxygen was being delivered to the peanut briquettes or the combustion temperature was low and may be a result of briquette size, density, and particle distribution. The difference in emissions profile cannot be confidently attributed to the peanut shells alone. Because we originally set out to make a qualitatively good briquette, we have not varied the binder or binder to peanut ratio yet in emissions testing. Our choice of yucca might actually be the cause of higher emissions, but further work needs to be done to determine this. Higher starch content may cause worse combustion performance, but according to Bullis, the higher CO2 production is offset by CO2 sequestered during plant growth [22]. This is an area that needs further research, however we know we need to find a binder that has the optimal compromise between briquette emissions and briquette durability. Controlling the grain size is another parameter that needs to be investigated, as it may affect combustion efficiency.

### *4.4 Implementation Model*

We decided to investigate three possible implementation models to promote peanut shell briquetting:

(1) To sell a joint Universal Nut Sheller (UNS) & briquetting system to individuals or communities, including training, so that these communities can make their own fuel briquettes and either use them or sell them;

(2) To sell a joint UNS & briquetting system, including training, to a larger-scale operator (e.g. commercial groundnut farmer, etc) who acquires feedstock from his/her own fields and from those of other farmers, then makes and sells back briquettes (either as pressed agricultural waste or as charcoal); or

(3) To sell a joint UNS & briquetting system, including training, to an operator who can travel from community to community, charging individuals on a per use basis to both grind shells and produce fuel briquettes from those shells

These models all deal with two common questions:

- Do you promote centralized or decentralized production?
- Do you expect the briquettes to be marketable (i.e. revenue-generating), or do you expect them to be for –own use?”

In the following sections, we offer some preliminary discussion of these factors.

### 4.4.1 Production capacity is limited for individual smallholders

Tests in our lab indicate that shells form approximately 25% of peanut mass. Drawing from International Food Policy Research Institute reports, we assume the average Malawian smallholder cultivates 1.75 hectares and that a majority of smallholdings are in the range of 0.5 to 3 hectares [23]. According to the Malawi Agriculture Ministry’s 2008 land survey, yields for peanuts averaged 1.13 tons per hectare [24]. Therefore, presuming average yields, the average smallholdings can produce a maximum of approximately 2 tons per year. Given that shells make up 25% of peanut weight, this yields 500 kg of shells. The average weight of our briquettes is 16 g; therefore, maximum conversion of waste could produce roughly 30,000 briquettes. If we assume that the average household has 6 people and averages roughly 600 kg of fuel wood use per capita per year [1], [23] and that briquettes can substitute fully for fuel wood, then the annual production of peanut shell briquettes could maximally supply 14% of household needs, or 50 days of fuel for an average rural household. (For urban households, fuel use is roughly double on a per capita basis, [1] although it is unclear if household size is the same.)

Note that these numbers represent theoretical maxima based on averages. Smallholding sizes vary substantially, and yields can be based on very local factors, affected by climactic patterns. Peanut harvests occur annually during June and July [14]. It is unlikely that households will be convinced to work on briquette production during harvest, thereby requiring the storage of peanut shell waste for later use. Thus, it is likely only a fraction of shells will be gathered and converted into fuel briquettes, and the briquettes will not act as perfect substitutes for fuel wood (see Section 3.2). Also, smallholders are not likely to use their entire plot for peanuts. Therefore, actual smallholding supply can reasonably be expected at a fraction of the level mentioned above.

Given the small fraction of household fuel needs that peanut briquettes could supply, it is unclear whether individual smallholders would consider the effort worth it. Changing fuel use—and thus cooking practices—is challenging even when benefits are substantial.

Moreover, it is possible that briquette production with current processes may actually take *more* time than fuel wood collection, not less. In practice, we found that passing the shells a second time through the UNS, preparing the cassava binder, and forming the briquettes could average as low as 1 person-minute per briquette. To produce one day of fuel for an average household (10 kg), approximately 600 briquettes would be needed, translating to approximately 10 person-hours. This is substantially more time than would be required for fuel wood collection in even highly deforested areas. While it is not realistic to assume full substitution for fuel wood, even a partial substitution would demand substantial time, and the perceived "cost" of production in time and effort may dissuade individual households from adoption.

Process improvements can lower this time requirement—for example, using agricultural presses that produce several briquettes simultaneously. (Given that agricultural waste presses have been observed in use in Malawi, [14] it seems reasonable to expect that time costs can be overcome.) Also, centralized processors that can utilize a larger capacity of shells may be able to drive time-per-briquette down and potentially create a briquette that is competitive with wood in terms of "time cost."

### 4.4.2 Linkage between centralization of production and marketability of briquettes

Making briquettes is not straightforward; beyond the choice of feedstock, the factors involved in briquette production include but are not limited to: compression, particle size, choice of binder (if any), pre-treatment of feedstocks (if any), shape, moisture content, and drying process. In Section 3.1 above, we offer recommendations with respect to many of these factors. Nonetheless, even given an "optimal" briquette design, the quality of a particular briquette made by one artisan is likely to differ substantially from that of a neighboring artisan. While this lack of standardization may not pose a significant challenge to household use—that is, briquette use by the briquette makers themselves—varying quality that results in sub-standard briquettes would create a risk of destruction in transport, poor combustion, and other negative factors. These risks pose a barrier to marketability of peanut briquettes and acceptance of them as a substitute for fuel wood or charcoal (whose properties are often well understood).

Thus, it appears that the centralization of production and the marketability of briquettes are linked, and that decentralized production is likely to predicate non-market “own use.”

### 4.4.3 Individual ownership preferable to community ownership

Without actual presence in the field, we have not been able to explore this area extensively. Nonetheless, drawing on team member observations in other developing communities and consideration of the use of UNS to date, it appears that individual ownership and operation of a briquetting system is more likely to succeed than community ownership and operation. David Campbell, a Peace Corps member in Senegal promoting and conducting training on the UNS, captures our main concern:

> “Community cohesion can be a really sticky issue, especially when there are shared assets and shared work duties. Infighting could ruin the whole initiative, but I think an individual could really make it work by collecting the peanut waste from the entire community.” [25]

Amanda Shing, a MIT D-lab affiliate currently in Malawi, put it this way:

> “Collectively, if people are willing to share money with each other from other families, then they can join together and make a business, but it is not extremely common. It’s more common that one person/family, who is more well off, will hire piece workers to help.” [14]

Moreover, a simple role-playing exercise we conducted revealed to us community operation presents more logistical complexity than individual operation, as it would require households to coordinate shell processing; this lends itself to disagreements over each participants’ share in the production effort and briquette yield. While individual operation might seem to limit production capacity, ultimately the capacity seems most limited by press design and feedstock supply, rather than labor—as operating a UNS-briquette production system would occupy 3-4 people at most.

Most importantly, with individual operation only one party needs to be convinced to adopt. Community operation requires the agreement and continued coordination of multiple parties—an uncertain proposition, given the novelty and inevitable initial learning challenges to production. Furthermore, an individual invested in a briquette-making system is more likely to drive production than a community, where investment (and responsibility) is distributed. (Of course, a cohesive community with highly motivated and competent leadership could overcome these problems, but that is not an easily replicable approach.)

### 4.4.4 Recommended Implementation

Relying on a centralized, larger-scale producer is the most likely implementation model to succeed. Briquette quality can be better controlled, and scale efficiencies can make briquette production low in time cost relative to fuel wood collection and allow for supply outside of harvest seasons. A commercial peanut processor or charcoal producer would be best positioned to succeed, given their previous experience in larger-scale processes—although an enterprising smallholding family might be capable as well. It's likely that this operator would be of middle- to high-income status in the community, as they would need to recruit others to work for them. This operator could both use their own peanut shell wastes and collect shell wastes from smallholders, perhaps at nominal prices to incentivize collection. (Furthermore, this operator could collect other agricultural wastes and convert such wastes into charcoals as appropriate.)

The briquette system and training should exploit moments of conscious behavior change (i.e. purchase of a new technology) and be packaged with the sale of the universal nut sheller. The adoption of the UNS provides the ability to reprocess shell wastes, and training on briquette production can be piggybacked into training on the construction and use of the UNS. Furthermore, creative marketing should be undertaken; fundamentally, using shell wastes as fuel requires shifting perceptions and cultural acceptability, and promotional images and videos of peanut shell briquettes can make headway.

While centralization would lower the barriers to marketing briquettes, the value proposition of peanut shell briquettes requires extensive consumer testing (see Section 5.1).

### 4.4.5 Marketability

Charcoal currently sells for MK 50 (roughly $0.33 at current rates) per half grocery bag, which we crudely estimate to weigh 3 kg [26]. The status quo will remain dominant unless the peanut fuel briquettes have comparable quality and offer significant savings. While actual prices need to be tested in the marketplace, it is reasonable to expect that peanut fuel briquettes should have to be half the price of charcoal—that is, MK 25—for quick take-up.

The official minimum wage of MK 167 (just over $1) per day in Malawi is hardly enforced and does not apply to subsistence agriculture; nonetheless it provides a point of comparison [27]. An eight-hour workday would imply that the minimum wage is 20 MK/hr. Assuming full substitution for charcoal, an equivalent bag of peanut shell briquettes would consist of approximately 200 briquettes. This in turn would require 3.3 person-hours to produce. At minimum wage, this implies a labor cost of MK 67 for a bag—nearly three times the proposed selling price of MK 25 per bag!

A much lower wage is required to make briquettes cost-competitive. Assuming that labor costs make up only a fraction of sales price, the above calculations imply a that a wage of roughly MK 3-4/hr—roughly five times lower than the minimum wage—would be required to make a MK 25 bag of briquettes. From this admittedly highly simplified standpoint based on crude assumptions, the wage associated with competitively-priced briquette production would appear to be very low—though perhaps not out of the realm of possibility for rural agrarian workers.

These numbers are based on crude assumptions and require refinement to be considered accurate. Nonetheless, they reveal that the costs of briquette production require a time-value of labor that is likely very low, and it is left for field work to determine how people value their time—and thus, whether it makes economic sense for people in rural agrarian areas to put effort toward briquette production. It also indicates that the margin associated with briquette production is potentially quite small, raising questions as to whether potential operators would be willing to pay for the system and training. A low payback rate is essentially a non-starter in developing countries, where discount rates are generally quite high due to the lack of capital and risks of business failure [28].

#### 4.4.6 Stakeholder Analysis

**As outlined in**

Table 4 below, we see peanut farmers (producers) and rural cooks (consumers) at the most important allies in bringing to fruition a peanut briquette project. It is important to bear in mind that current fuel suppliers are potential competitors, and that a strategy to address them—for example, having them promote and sell briquettes—could be helpful. The only particularly significant opponents we anticipate are other organizations working on related domains, be that stoves, household fuel, local deforestation, etc. They are potential partners, presuming that the implementation of a peanut briquette system furthers their goals; however, it can also be interpreted as encroachment, and one should be thoughtful in approaching these organizations.

## Table 4: Stakeholder Analysis

| Stakeholder | Potential interest in project | Potential Impact on Project | Ally? Competitor? Opponent? None? | How important (10 = vital, 1 = unessential) |
|---|---|---|---|---|
| Urban cooks | Fuel burnability, making food, time spent of cooking, buy fuel | Demanders | None | 7 |
| Rural cooks | Fuel burnability, making food, time spent of cooking | Demanders | Ally | 10 |
| Rural fuelwood gatherers | Gather wood, sell to urban consumers | Main communicators of briquettes to market | Ally | 7 |
| Peanut farmers | Suppliers of ag wastes, extra income | May want ag wastes for something | Ally; opponent if they already use wastes for something else | 9 |
| Peanut consumers | Want to keep eating peanuts | Drive demand for peanuts | None | 1 |
| Fuelwood middlemen/vendors | Selling fuel, making money | Undermine/compete; Main communicators of briquettes to market | Potential ally, potential competitor | 3 |
| Charcoal makers/vendors | Selling fuel, making money | Undermine/compete or adopt; Main communicators of briquettes to market | Potential ally, potential competitor | 4 |
| Community Leadership | Organizing people to do stuff, prestige of community/own position | Determine access to communities | Potential ally, potential opponent | 8-10 depending on implementation |
| Government | Look good to constituents, preserve position | Access to communities | Ally or opponent | 1 |
| Full Belly Project | Expand operations, get more donors, have impact | Resources, implementation style | Ally | 8 |
| Other NGOs focused on livelihoods/fuel | Community relations, donor relations, promoting own projects | Can impact community access and reputation of product | Potential ally, potential competitor | 3 |

## 5 Summary and Conclusions

In this report we have described a workable process and design for a peanut shell briquette, as well as a recommended means of implementation. However, the barriers to briquette adoption are not trivial and need to be addressed. Peanut shell briquette production is a time intensive process—so much so that production only saves time from comparable fuel wood gathering when briquettes are produced at scale. The most functional briquette was a donut-shaped briquette comprised of a 1 to 6 yucca to peanut shell ratio. The binder we use is a food source, and it may be anathema to some individuals to use food for fuel. The actual cooking experience with peanut shell briquettes requires more constant attention than wood or charcoal fires, and we anticipate that users will be slow to take up the briquettes, if at all.

We also found that the emissions from peanut shell briquettes are not any better than wood—and could, in fact, be significantly worse. Furthermore, we found that as our process and product are currently designed, peanut shell briquettes are not likely to be market viable, as achieving competitive prices may require extremely low-priced labor and the payback time for such a system may be very long.

These factors together lead us to conclude that the further development of peanut shell briquettes should not continue in the same, narrow vein in which we have proceeded. Fundamentally, our project has encountered many of the same challenges that agri-waste fuels generally encounter. Without compelling data to indicate peanut shells as superior to other wastes for fuel use, it does not make sense to narrow the design process to focusing on peanut shells.

Finally, it is crucial to note that efforts to displace fuel wood and efforts to improve respiratory health may run contrary to each other, as utilizing agricultural waste may tackle the former at the expense (or at least non-improvement) of the latter. Future work would do well to bear in mind this tradeoff and deal with it mindfully, rather than hope for a “best of all worlds” approach.

## 6 Future Research

Much of the future research we recommend is in line with the general concerns of agricultural waste fuels generally. It is beyond the scope of this paper to recount them all, but below we list some recommended directions based on the work we have presented in this report.

In terms of the briquette design, alternative binders should be considered if the project is to be expanded outside of Malawi since we primarily considered cassava-based binders. Also, because the peanut shell is only about 25% of the total mass of a peanut, peanut shells can be mixed with other types of agricultural waste to create briquettes. The ideal scenario would be mixing the peanut shells with something that burns better than peanut shells alone and would not require a binder.

During the briquette emissions testing we were unable to measure the moisture content of the briquettes. This information would be useful in order to improve combustion efficiency and ease of lighting, so it is a metric that should be measured in future testing. Emissions testing of wood charcoal using the Darfur stove setup would also be ideal for comparing with the peanut shell briquettes, since this is what is predominantly used in Malawi as an alternative to wood. Also, the emissions from the starch-based bindersshould be characterized since the peanut shell briquettes proved to be worse than wood and starchy substances are known to produce a lot of black smoke because of their carbon content.

Beyond simple design and testing, however, implementation appears to be an enormous challenge. Amanda Shing observes thusly:

> ―There are presses for agricultural waste briquettes here in Malawi already. **It's really more of the marketing, distribution, and cultural acceptance that will make briquettes successful,** so coming up with a good dissemination plan to create the demand and usage is what may lead to success." [14]

Consumer testing is a critical requirement of any product. Peanut shell briquettes, as specified in our recipe, need their trial by fire. Future researchers could share these and similar agricultural waste briquettes with urban and rural cooks in Malawi, observe their cooking behavior, and elicit their feedback. With a refined recipe, future researchers could also attempt to reveal perceived value by asking women to determine how big a bag of briquettes they'd accept to give up a bag of charcoal.

Fundamentally, any future research needs to figure out how to disseminate agricultural waste briquettes, presuming that a briquette can be developed that receives encouraging responses from consumer testing. This involves an understanding of the economics of biomass fuels to determine what is cost-competitive and an analysis of production processes to anticipate production costs, likely revenues, and thus likely payback time. Moreover, because agricultural waste briquettes require better cultural acceptance, future research must explore effective methods of shifting perceptions through promotional images, video, and other means of cultural communication—both for briquettes themselves and the systems that groups like FPB would like to sell to operators.

## 7 Acknowledgments

We thank Jock Brandis and the folks of the Full Belly Project for providing us an opportunity to work on an interesting and involved design challenge, as well as their support in providing us with materials. Tim Anderson provided insightful technical advice, and Amanda Shing acted as our eyes and ears in Malawi; we are grateful to both of them for taking the time to help us. We would like to thank Thomas Kirchstetter and Odelle Hadley at LBNL for teaching us how to do the emissions testing. Finally, we wish to acknowledge Susan Addy & Johanna Mathieu for continuing the instruction of CE290 in Ashok Gadgil’s absence; their enthusiasm, insight and knowledge made the course both thought-provoking and engaging.

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# 9 Appendix

## *9.1 In-Class Feedback Session*

On March 30, 2010 we provided our classmates with the following survey to gauge the durability of the briquettes that had been produced in our first briquette-making session. We also had discussion questions that we posed, to help us walk through some of the problems that had arisen mid-way through the project. The survey questions and a summary of the results follow.

***Questions:***

a) Looseness (5 = falls apart in the hand, 1 = very durable)

1 2 3 4 5

b) Transportability (5 = doesn't withstand transportation beyond home, 1 = survives Africa ride on bicycle)

1 2 3 4 5

c) Aesthetics (5 = not desirable to buy at any price, 1 = highly desirable)

1 2 3 4 5

Qualitatively assess the overall durability of the briquette:

***Qualitative Results:***

| | Mixture | Peanut Shells | Label | Quest. | Rating | Comments |
|---|---|---|---|---|---|---|
| Corn Starch | 1 $H_2O$ : 1 Starch | 2.5 | B | a | 5 | Breaks very easily - ECAR |
| | | | | b | 5 | |
| | | | | c | 3 | |
| Plantains | 1 | 6 | B2 | a | 4 | Fell apart easily - Biochar |
| | | | | b | 4 | |
| | | | | c | 3 | |
| | 1 | 4 | | a | 2 | Seems to be most durable - Patsari Stove |
| | | | | b | 2 | |
| | | | | c | 2 | |
| | 1 | 6 | | a | 5 | Smells good, but also fell apart when touched - Patsari Stove |
| | | | | b | 4 | |
| | | | | c | 2 | |
| | 1 | 5 | | a | 3 | *n/a* - ECAR |
| | | | | b | 3 | |
| | | | | c | 2 | |
| | | | | a | 3 | Smells good, feels wetter - Water storage |
| | | | | b | 2 | |
| | | | | c | 3 | |
| Tapioca | 1 $H_2O$ : 1 Tapioca | 3 | A | a | 5 | Fell apart in hand - Biochar |
| | | | | b | 5 | |
| | | | | c | 2 | |
| | 1 $H_2O$: 1 Tapioca | 3 | C | a | 5 | Fell apart when touched - Patsari Stove |
| | | | | b | 5 | |
| | | | | c | 4 | |
| | | | | a | 3 | Much too loosely packed; much drier, whiter - Water Storage |
| | | | | b | 2 | |
| | | | | c | 3 | |
| Wet Tapioca | 1 | 6 | B | a | 2 | Held up pretty good - Biochar |
| | | | | b | 2 | |
| | | | | c | 3 | |
| | 1 | 6 | C | a | 2 | *n/a* - ECAR |
| | | | | b | 2 | |
| | | | | c | 2 | |
| | 1 | 6 | A | a | 2 | Best durability of the three - Water Storage |
| | | | | b | 2 | |
| | | | | c | 3 | |

***Discussion:***

Are there any suggestions for avoiding the excess use of tinder or other fire starting aids given that lighting the briquettes has been a challenge?

- Water Storage: Winnow fibrous matter from shells. Is cold start really that important? Just use them only in hot start
    - Might be a perceptions issue if they are hard to light
- Patsari Stove: Something will have to be used to start it. Check with how they currently start fires. An over or stove to keep in heat and reduce heat losses from wind. Using a slower burning fuel will also help. Quick burning like rubbing alcohol could be detrimental to pulling heat/flame away.
- Biochar: Flammable binder? Coals from old fire, keep old coals to get new fire with peanut hull briquettes?

What do you think of the issues surrounding use of potential food sources as a binder (specifically plantains)?

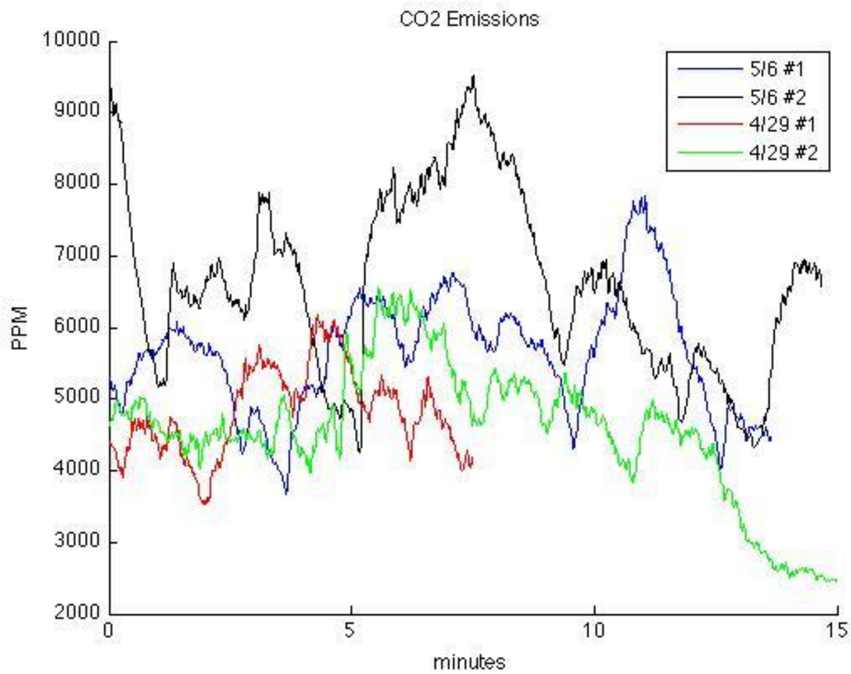
- Water Storage: Maybe plantain peels have starch? Don't use food, use food waste.
    - Concern if people have to plant new crops
    - Sell pre-made binders?
- Patsari Stove: Maybe use rotten or other undesirable food? What's the availability of plantains in Malawi? Maybe find another food source that is local and easy to find

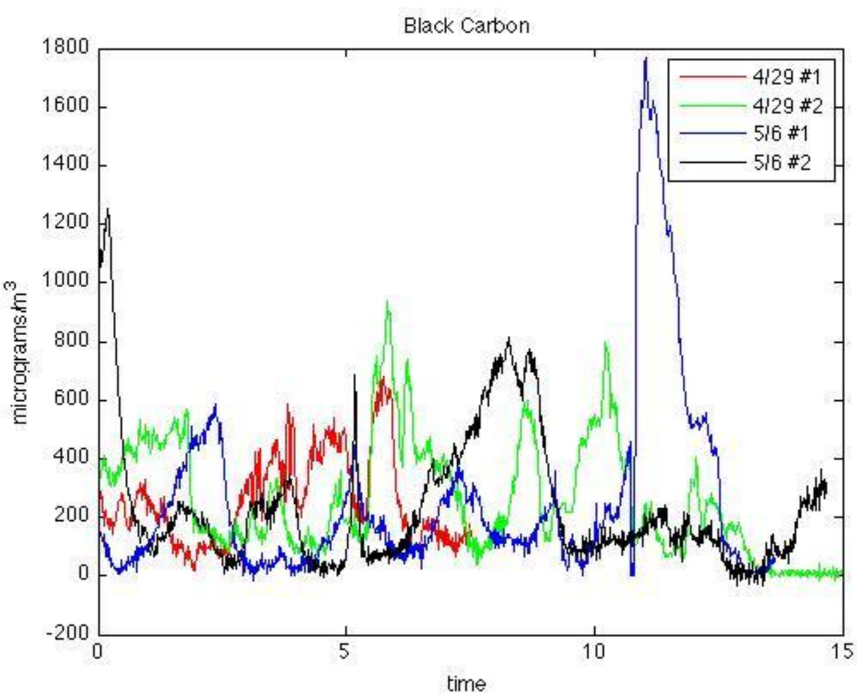
Given that Agricultural waste is already used in some briquettes, do you think this strays too far towards reinventing the wheel? Any suggestions?

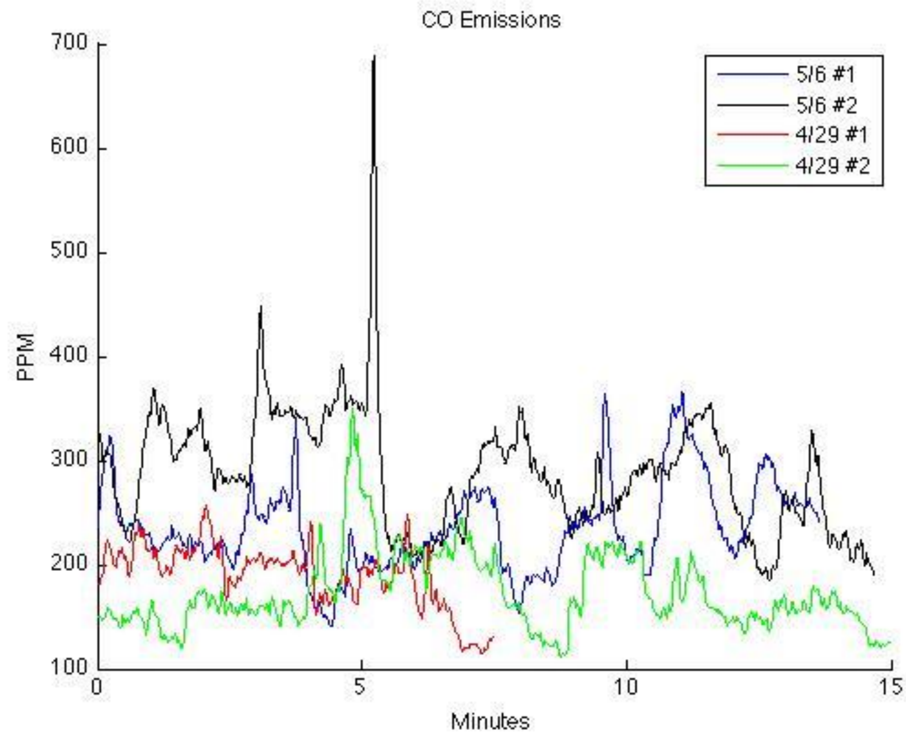
- ECAR: No, it seems like a good solution to a waste product. You can get a valuable product from waste, so why not.

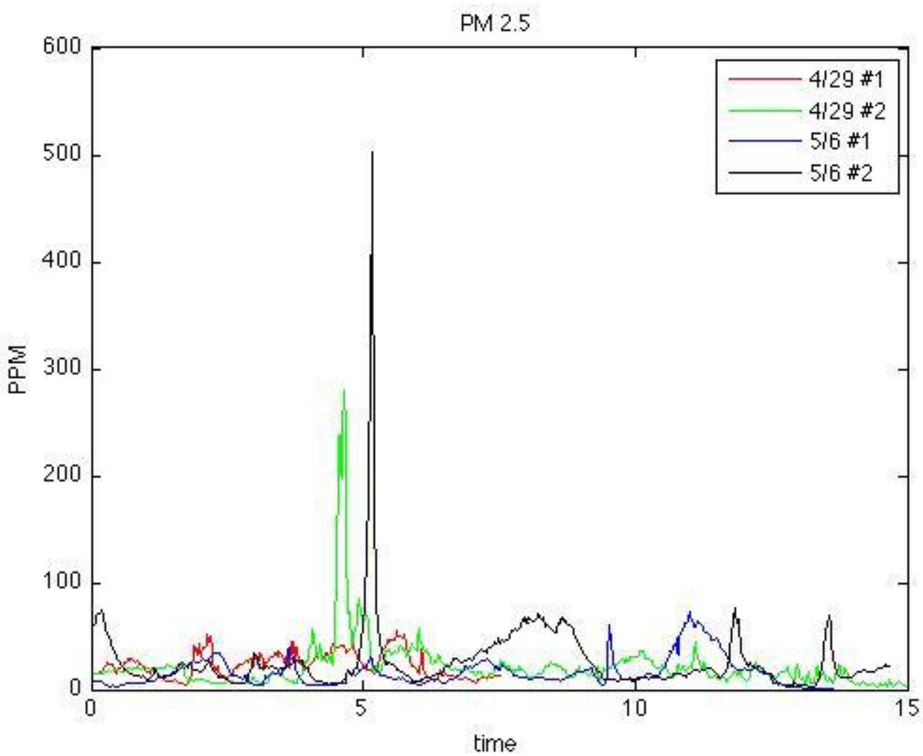
### *9.2 Additional Figures - Quantitative Results*

Included here are raw emissions figures for four peanut briquette emissions trials during the 15-minute boil time frame. This data was used to calculate emissions values presented in Table 3.




CO Emissions
PPM
Minutes
5/6 #1
5/6 #2
4/29 #1
4/29 #2
700
600
500
400
300
200
100
0
5
10
15


PM 2.5
PPM
time
4/29 #1
4/29 #2
5/6 #1
5/6 #2
600
500
400
300
200
100
0
0
5
10
15

## 9.3 Quantitative Testing Notes

| | | | | | | |
|---|---|---|---|---|---|---|
| **Test Date** | 4/29/2010 | | **Sample Flow** | | 1.86 | L/min |
| **Test Time** | 14:50 | | **Dilution Flow** | | 19.3 | l/min |
| **Testers** | Stephen, Sean, Tammy | | **Starting Fire** | | 4 sheets, 34.3. g wood | |
| | | | **Ash** | | 14.8 | g |
| **Minutes** | **Seconds** | **Water Temp** | **Briquette** | **Comments** | | |
| 58 | 16 | | 13.3 | | | |
| 59 | 30 | 21 | 14.4 | | | |
| 0 | 22 | N/A | 14.5 | | | |
| 0 | 49 | N/A | 0 | | | |
| 1 | 5 | N/A | 13.8 | Bellows | | |
| 1 | 30 | 29 | 0 | | | |
| 1 | 45 | 33 | 12.8 | | | |
| 2 | 37 | 34.7 | 17.4 | | | |
| 3 | 11 | 40.1 | 15 | | | |
| 4 | 29 | 50 | 15.5 | | | |
| 6 | 1 | 52.3 | 15.4 | | | |
| 6 | 26 | 56.7 | 13.6 | | | |
| 7 | 7 | 61.8 | 11 | | | |
| 8 | 0 | 73.5 | 15.6 | | | |
| 9 | 56 | 78 | 13.5 | | | |
| 10 | 40 | 81 | 14.9 | | | |
| 11 | 23 | 83.7 | 14 | | | |
| 12 | 0 | N/A | 0 | Bellows | | |
| 12 | 20 | 87.9 | 14.3 | | | |
| 13 | 5 | 93.3 | 14.2 | | | |
| 14 | 21 | 96.4 | 13.3 | Boil | | |
| 15 | 4 | 99.8 | 12.4 | Boil | | |
| 16 | 20 | 100.4 | 14.5 | Boil | | |
| 18 | 7 | 99.6 | 14.2 | Boil | | |
| 19 | 47 | 99.5 | 16.5 | Boil | | |
| 20 | 8 | 100.5 | 14 | Boil | | |
| 21 | 48 | 100.2 | 13.9 | Boil | | |
| 23 | 59 | 99.5 | 14.2 | Boil | | |
| 25 | 48 | 98.7 | 19.6 | Boil | | |
| 26 | 20 | 99.2 | 19.8 | Boil | | |
| 27 | 5 | | 0 | Bellows | | |

| | | | | |
|---|---|---|---|---|
| 27 | 16 | 96.4 | 14.6 | |
| 28 | 43 | | 0 | Bellows |
| 31 | 2 | | 0 | Bellows |
| 32 | 29 | 93.9 | 0 | Bellows |
| 32 | 40 | | 0 | Bellows |
| 32 | 45 | | 0 | Bellows |
| 37 | 1 | | 0 | Bellows |
| 39 | 30 | | 0 | |

| | | | | | |
|---|---|---|---|---|---|
| **Test Date** | 4/29/2010 | **Sample Flow** | | 1.86 | L/min |
| **Test Time** | 15:50 | **Dilution Flow** | | 19.3 | l/min |
| **Testers** | Stephen, Sean, Tammy | **Starting Fire** | | 4 sheets, 34.3. g wood | |
| | | **Ash** | | 19 | g |

| **Minutes** | **Seconds** | **Water Temp** | **Briquette** | **Comments** |
|---|---|---|---|---|
| 50 | 40 | 26.5 | 0 | |
| 51 | 45 | 30.1 | 13.1 | |
| 52 | 0 | 32 | 14.1 | |
| 52 | 10 | | 0 | |
| 52 | 32 | 35.6 | 16.1 | |
| 52 | 46 | | 0 | |
| 53 | 40 | 39.7 | 17.1 | |
| 54 | 30 | 42.2 | 13.7 | |
| 55 | 32 | 46.6 | 14.2 | |
| 56 | 16 | 50.7 | 18.5 | |
| 58 | 9 | 61.6 | 14.8 | |
| 59 | 10 | 69.1 | 21.1 | |
| 0 | 38 | 79.5 | 15.2 | |
| 2 | 10 | 88 | 15.2 | |
| 3 | 19 | 94.5 | 19 | |
| 4 | 20 | | 0 | Boil |
| 5 | 40 | 101.3 | 27.1 | Boil |
| 7 | 51 | 101.2 | 7.2 | Boil |
| 8 | 22 | 101.3 | 17.4 | Boil |
| 8 | 38 | | 0 | Boil |
| 9 | 48 | 101.4 | 17.7 | Boil |
| 10 | 1 | | 0 | Boil |
| 11 | 19 | 101.3 | 18.5 | Boil |

| | | | | |
|---|---|---|---|---|
| 12 | 45 | 101.4 | 12 | Boil |
| 14 | 36 | 101.3 | 23.6 | Boil |
| 23 | 47 | | 0 | |
| 24 | 55 | | 0 | End |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Test Date** | 5/6/2010 | | **Sample Flow** | | 1.69 | L/min |
| **Test Time** | 13:15 | | **Dilution Flow** | | 19.4 | l/min |
| **Testers** | Stephen, Sean, Tammy | | **Starting Fire** | | 4 sheets, 35.2. g wood | |
| | | | **Ash** | | 13.6 | g |

| Minutes | Seconds | Water Temp | Briquette | Comments |
|---|---|---|---|---|
| 23 | 52 | 23.9 | N/A | Lighting |
| 24 | 47 | 26 | 12.9 | |
| 25 | 5 | 331.3 | 11.3 | |
| 25 | 12 | 33.4 | 14.2 | |
| 25 | 23 | 35.7 | 17 | |
| 26 | 50 | 45.6 | 15.7 | |
| 27 | 20 | 49.6 | 15.2 | |
| 28 | 40 | 60.5 | 12.4 | Bellows |
| 29 | 0 | N/A | 0 | |
| 30 | 15 | N/A | 14.6 | |
| 31 | 13 | N/A | 13 | |
| 31 | 26 | N/A | 14.8 | |
| 32 | 23 | | 0 | Bellows |
| 33 | 27 | N/A | 13.8 | |
| 34 | 36 | N/A | 11.3 | |
| 35 | 37 | N/A | 12.9 | |
| 37 | 49 | N/A | 15.9 | |
| 38 | 41 | 100.6 | 11.8 | Boil |
| 41 | 9 | 100.3 | 13.8 | Boil |
| 42 | 8 | 100.3 | 15.6 | Boil |
| 42 | 8 | 100.3 | 0 | Boil |
| 43 | 14 | 100.2 | 13.2 | Boil |
| 44 | 40 | 100.8 | 14 | Boil |
| 46 | 13 | 100.8 | 14.7 | Boil |
| 48 | 4 | 100.3 | 12.5 | Boil |
| 48 | 50 | 100.8 | 11.2 | Boil |
| 51 | 20 | 99.8 | 11.1 | Boil |

| | | | | |
|---|---|---|---|---|
| 52 | 44 | 99.7 | 0 | Boil |
| 53 | 20 | 99.1 | 0 | Boil |

| **Test Date** | 5/6/2010 | | | **Sample Flow** | 1.69 | L/min |
|---|---|---|---|---|---|---|
| **Test Time** | 13:15 | | | **Dilution Flow** | 19.4 | l/min |
| **Testers** | Stephen, Sean, Tammy | | | **Starting Fire** | 4 sheets, 35.2. g wood | |
| | | | | **Ash** | 12.2 | g |
| **Minutes** | **Seconds** | **Water Temp** | **Briquette** | **Comments** | | |
| 8 | 9 | 25.1 | 0 | | | |
| 8 | 50 | 25.5 | 12.8 | | | |
| 9 | 0 | 26.5 | 19 | | | |
| 9 | 24 | 29.7 | 13.1 | | | |
| 10 | 34 | 37.7 | 14.6 | | | |
| 12 | 1 | 48.3 | 14 | | | |
| 13 | 18 | 56.3 | 16.3 | | | |
| 14 | 40 | 66.4 | 14.8 | | | |
| 15 | 50 | | 0 | bellows | | |
| 16 | 10 | 74.4 | 15.3 | | | |
| 18 | 23 | 83.9 | 15.7 | | | |
| 18 | 34 | | 0 | bellows | | |
| 18 | 52 | 85.5 | 13.1 | | | |
| 19 | 26 | | 0 | bellows | | |
| 19 | 40 | 87.3 | 12 | | | |
| 20 | 50 | 92.2 | 15.7 | | | |
| 22 | 22 | 100 | 0 | bellows | | |
| 23 | 16 | 100.9 | 13.3 | Boil | | |
| 23 | 23 | | 0 | bellows | | |
| 23 | 54 | 100.5 | 13.8 | Boil | | |
| 25 | 0 | 100.9 | 15.2 | Boil | | |
| 25 | 5 | | 0 | be | | |
| 26 | 59 | 100.6 | 17 | Boil | | |
| 27 | 17 | 100.4 | 15.6 | Boil | | |
| 27 | 21 | | 0 | bellows | | |
| 28 | 52 | 101.1 | 16.2 | Boil | | |
| 31 | 36 | 100.8 | 14.9 | Boil | | |
| 33 | 50 | 100.4 | 14.9 | Boil | | |
| 35 | 39 | 99.8 | 16.2 | Boil | | |
| 37 | 3 | 101 | 0 | bellows | | |